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Research article

Outdoor Walkway Flooring from Natural Rubber and Reclaimed Rubber Blends with Superior Environmental Resistance

Tiptiwa Sampantamit[1], Apinan Aueaungkul[2], Pornsiri Toh-ae[3], Panita Sumanatrakul[4], Suppachai Sattayanurak[5], and Weerawut Naebpetch[6*]

[1] Faculty of Science and Digital Innovation, Thaksin University, Phatthalung, 93210, Thailand
[2] Faculty of Economics and Business Administration, Thaksin University, Songkhla, 90000, Thailand
[3] Center of Rubber Technology for Community, Faculty of Engineering, Thaksin University, Phatthalung, 93210, Thailand
[4] Faculty of Engineering, Thaksin University, Phatthalung, 93210, Thailand
[5] Faculty of Engineering, Thaksin University, Phatthalung, 93210, Thailand
[6] Faculty of Engineering, Thaksin University, Phatthalung, 93210, Thailand
* Correspondence: weerawut.n@tsu.ac.th

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Abstract: This study systematically investigated the effects of reclaimed rubber (RR) content on the mechanical properties and accelerated aging resistance of natural rubber (NR) vulcanizates for outdoor walkway flooring applications. Six formulations were prepared with NR/RR ratios ranging from 100/0 to 50/100 parts per hundred rubber (phr), maintaining a total rubber content of 100 phr after accounting for the 48-50% actual rubber content in reclaimed rubber (confirmed by thermogravimetric analysis showing 55% mass loss at 350-400°C). Results demonstrated that increasing RR content from 0 to 100 phr progressively decreased tensile strength and elongation at break, while hardness and 300% modulus exhibited slight increases due to residual cross-links and higher filler concentrations in reclaimed rubber. Notably, accelerated aging tests (ASTM D573: 100°C for 22 hours; ASTM G154: UV-A 0.89 W/m² at 340 nm, 60°C for 8 hours, followed by condensation at 50°C for 4 hours, total 168 hours) revealed substantial improvements in aging resistance with increasing RR content. The percentage decrease in tensile strength after aging diminished progressively as RR content increased. The optimized formulation containing 100 phr reclaimed rubber was selected for commercial production. Despite having a relatively lower tensile strength compared to virgin NR formulations, this composition provided adequate mechanical performance while demonstrating superior resistance to environmental degradation. Compression molding at 170°C for 8 minutes produced 1 m² × 0.06 m rubber tiles with anti-slip lozenge patterns. Implementation at a commercial café yielded positive user feedback and achieved an approximately 30% cost reduction compared to virgin rubber formulations, supporting the sustainable utilization of rubber waste.

Keywords: Natural rubber; reclaimed rubber; outdoor walkway; glooring

1. Introduction

With the growing number of elderly individuals in society, tourism-related businesses have increasingly adapted their facilities to accommodate better the needs of older customers, whose numbers continue to rise each year. One up-and-coming product designed to support this demographic is the rubber walkway. Rubber's natural flexibility makes it soft and comfortable to walk on, while also offering excellent slip resistance [1], helping to reduce the risk of falls. Typically, synthetic polymers are used to produce these walkway sheets due to their durability and resistance to wear, which contribute to a long service life. However, since Thailand is a leading global producer of natural rubber—and because it is plant-based and environmentally friendly—natural rubber presents an attractive alternative for walkway development. Despite its excellent flexibility, mechanical strength, and slip resistance, natural rubber has a major drawback: poor resistance to oxidation, which limits its durability in outdoor environments [2]. Therefore, to produce rubber walkway sheets suitable for outdoor use, it is essential to research ways to enhance the oxidation resistance of natural rubber, especially in terms of resistance to accelerated aging.

Previous research has consistently focused on enhancing the deterioration resistance of natural rubber. A widely used approach involves modifying its structure to improve its resistance to degradation [3-5]. Saengdee et al. studied the chemical modification of natural rubber at the latex stage under environmentally friendly conditions, aiming to enhance its thermal, ozone, and mechanical properties. Two sequential chemical modifications—epoxidation followed by hydrogenation—were performed in a one-pot system. Natural rubber latex (NRL) was first treated with in situ performic acid, formed from formic acid and hydrogen peroxide, to produce partially epoxidized natural rubber (ENR) latex. This product was then further modified through a hydrogenation reaction using hydrazine and hydrogen peroxide to target the remaining unsaturated units. After vulcanization, all modified NRs retained the excellent mechanical properties of natural rubber due to their ability to undergo strain-induced crystallization. Additionally, the modified NRs showed improved resistance to oil, solvents, and ozone compared to the unmodified NR. These findings suggest that hydrogenated epoxidized natural rubbers (HENRs) can overcome the limitations of natural rubber, potentially expanding its range of applications [4]. Another commonly used approach to enhance the aging resistance of natural rubber is by blending it with rubbers that possess excellent aging resistance properties [6-8]. Developing high-value reclaimed rubber (RR) plays a crucial role in promoting sustainability within the rubber industry. To achieve eco-friendly recycling of waste rubber and expand the applications of RR, a material with potential reinforcing and plasticizing effects on natural rubber (NR) composites was produced through a thermo-oxidative reclamation process. The degree of reclamation was regulated by varying the amount of soybean oil used. The plasticizing effect of RR was evidenced by a reduction in torque during vulcanization and an increase in elongation at break of NR/RR composites as the reclamation level increased. Additionally, incorporating RR enhanced the tensile strength, thermal stability, and rheological properties of the NR/RR composites. The formation of new bound rubber in the NR/RR system further confirmed the reinforcing effect of RR. Scanning electron microscope images revealed that the average particle size of RR reached the nanoscale, and its dispersion within the composites improved with higher degrees of reclamation, as indicated by the Payne effect. Overall, this study highlights the dual reinforcing and plasticizing functions of RR, contributing to its value-added use and expanded application potential [7].

Accordingly, this study adopted a method to enhance the properties of natural rubber by blending it with reclaimed rubber. The effects of different reclaimed rubber contents on the mechanical and aging resistance properties were investigated. The formulation that demonstrated the most balanced overall performance was used to produce rubber flooring sheets, which were then applied in "Nai Susn Sri" commercial shop settings.

2. Experimental

2.1 Materials

Natural rubber (RSS #3, Thai Hua Rubber Public Co., Ltd., Thailand) and Reclaimed rubber (UCD-105, Union Commercial Development Co., Ltd., Thailand) were used as raw elastomers. Zinc oxide (White seal grade, UTIDS Enterprise, Co., Ltd, Thailand), Stearic acid (Imperial, Co., Ltd, Thailand), Carbon black (N550, Thai Tokai Carbon Product Co., Ltd., Thailand), Calcium carbonate (Caliofil100, Sand and Soil Industry Co., Ltd., Thailand), Paraffinic oil (Tudalen 13-grade, H&R ChemPharm (Thailand) Co., Ltd., Thailand), Paraffin wax (China Petroleum & Chemical Co., Ltd., China), Tetramethylthiuram disulfide: TMTD (Kawaguchi, Co., Ltd, Japan), N-cyclohexyl-2-benzothia zolesulphenamide: CBS (Kawaguchi, Co., Ltd, Japan) and Sulfur (Siam Chemical, Co., Ltd, Thailand) were used as rubber additives in the compound formulations.

2.2 Compound preparation

Rubber compounds were prepared using the formulations listed in Table 1, which were mixed using an open two-roll mill. The formulation does not use 100 phr of virgin natural rubber, as reclaimed rubber contributes approximately 50% rubber content. The compounding operation was initiated by masticating the natural rubber and reclaimed rubber for at least 3 minutes through the controlled distance of the front and back mill rolls (so-called nip width) at the initial mixing temperature. Zinc oxide, stearic acid, and paraffin wax were then added and mixed for approximately 3 minutes. Carbon black, calcium carbonate, and paraffinic oil were continuously incorporated in this step. The nip was changed twice, and finally, TMTD, CBS, and sulfur were added, resulting in a total mixing time of 25 minutes. The compounds were sheeted out at a thickness of 5 mm and stored at room temperature overnight.

Table 1. Rubber compound formulation.

Ingredients	Quantity (phr)					
Natural rubber (RSS#3)	100	90	80	70	60	50
Reclaimed rubber (UCD-105)	-	20	40	60	80	100
Zinc oxide	5	5	5	5	5	5
Stearic acid	1	1	1	1	1	1
Carbon black (N550)	40	40	40	40	40	40
Calcium carbonate (Caliofil100)	100	100	100	100	100	100
Paraffinic oil	15	15	15	15	15	15
Paraffin wax	2	2	2	2	2	2
TMTD	0.3	0.3	0.3	0.3	0.3	0.3
CBS	1.5	1.5	1.5	1.5	1.5	1.5
Sulfur	1	1	1	1	1	1
Curing time (t_{c90})	**5:50**	**6:08**	**6:49**	**7:23**	**7:50**	**8:00**

2.3 Sample preparation

Standard sheets were prepared by compression moulding the rubber compounds at 170 °C, each case for its optimal cure time (t_{c90}) determined by a Moving Die Rheometer, MDR (MDR-U6S, U-Can Dynatex Inc., Taichung, Taiwan) at a molding temperature. Test specimens for tensile properties were cut from the standard sheets using the standard dies (Die C dumb-bell, ASTM D412).

2.4 Measurements

2.4.1 Hardness

The test specimens, in the shape of a square, were 6×6 cm in size and 0.9 cm in thickness, as per ASTM D2240. They were measured using a hardness tester, Model GX-02 (Teclock Co., Ltd., Japan). Type A probes were used by measuring the four corners of the test piece and the center of the test piece, and then taking the average of the measured values.

2.4.2 Tensile properties

The tensile test was performed using a universal tensile testing machine (Tech Pro, CG Engineering Ltd., Part., Thailand) at a crosshead speed of 500 mm/min, according to ASTM D412. Tensile strength, 300% modulus, and elongation at break of specimens were measured five times. Finally, the average results were calculated.

2.4.3 Aging resistance

For heat aging resistance, samples prepared for the tensile test were placed in a hot-air oven at 100 °C for 22 h before the tensile measurement according to ASTM D573. The changes to properties, caused by aging in the oven, were assessed.

For weathering resistance, samples were placed inside the QUV machine. The testing cycle used UV-A at 0.89 W/m^2, 340 nm, at 60 °C for 8 h, followed by condensation at 50 °C for 4 h, with a total testing time of 168 h, as per ASTM G154. The changes to properties, caused by aging in the oven, were assessed.

3. Results and Discussion

As shown in Table 1, the theoretical rubber content should be 100 parts per hundred rubber (phr) in all formulations. However, when reclaimed rubber is incorporated, the total phr exceeds 100. This is because reclaimed rubber, produced through the recycling of end-of-life tires, comprises both rubber and non-rubber additives. According to the supplier of UCD-105 grade reclaimed rubber, the rubber content is approximately 48 % ± 3%.

To validate this, thermogravimetric analysis (TGA) was performed to examine weight changes in the material under thermal conditions. The results indicated that the reclaimed rubber exhibited approximately 55% mass loss at 350–400 °C (Figure 1), a temperature range associated with the decomposition of rubber and other polymers [9,10]. These findings are consistent with the manufacturer's data, confirming that the reclaimed rubber used in this study contains roughly 50% rubber and 50% additives. Therefore, after adjusting for rubber content, each formulation in this study maintained a consistent base of 100 phr rubber.

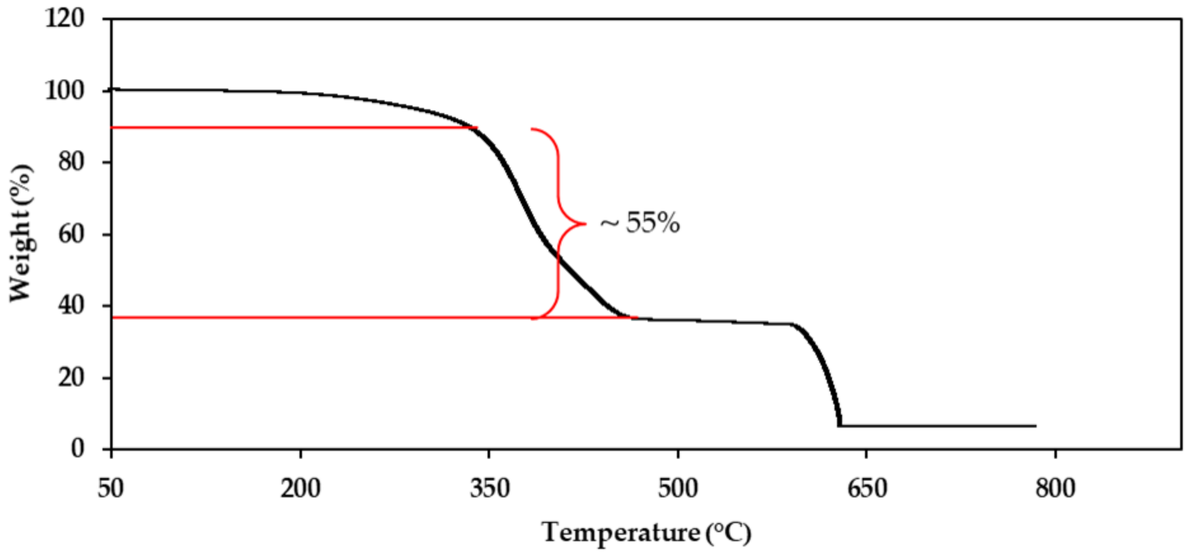

Figure 1. TGA curves of reclaimed rubber (grade UCD-105).

In developing a rubber compound suitable for outdoor walkway flooring, natural rubber was blended with reclaimed rubber. Natural rubber is renowned for its exceptional mechanical properties, but it is highly susceptible to degradation by oxygen, ozone, and UV radiation. Reclaimed rubber, on the other hand, has superior environmental resistance but suffers from significantly reduced mechanical strength due to prior thermal and mechanical degradation. Figure 2(A) illustrates the relationship between tensile strength, elongation at break, and reclaimed rubber content. As the proportion of reclaimed rubber increases, both tensile strength and elongation at break decline, particularly tensile strength. This is primarily due to the shortened molecular chains in reclaimed rubber, resulting from the recycling process, which lowers the average molecular weight and diminishes tensile strength. Rubber strength typically depends on molecular weight, cross-link density, and the presence of filler reinforcement. A higher reclaimed rubber content increases the filler concentration and simultaneously decreases molecular weight, compounding the reduction in strength [11].

Elongation at break also shows a mild decline with increasing reclaimed rubber. While reclaimed rubber has a lower molecular weight, it contributes to a broader molecular weight distribution in the blend, enhancing molecular mobility. As a result, the reduction in elongation is less pronounced, even at 100 phr of reclaimed rubber. Figure 2(B) presents the relationship between hardness, 300% modulus, and reclaimed rubber content. Both hardness and modulus were observed to increase slightly with a higher reclaimed rubber content. This can be attributed to the residual cross-links present in reclaimed rubber, which raise the overall cross-link density of the compound. Additionally, the reclaimed rubber contains fillers, which further contribute to increased hardness and modulus. Reclaimed rubber generally contains reinforcing fillers, as it is derived from tires. Consequently, increasing the proportion of reclaimed rubber also increases the filler content, enhancing rubber–filler interactions and resulting in higher hardness, in agreement with previous studies [11].

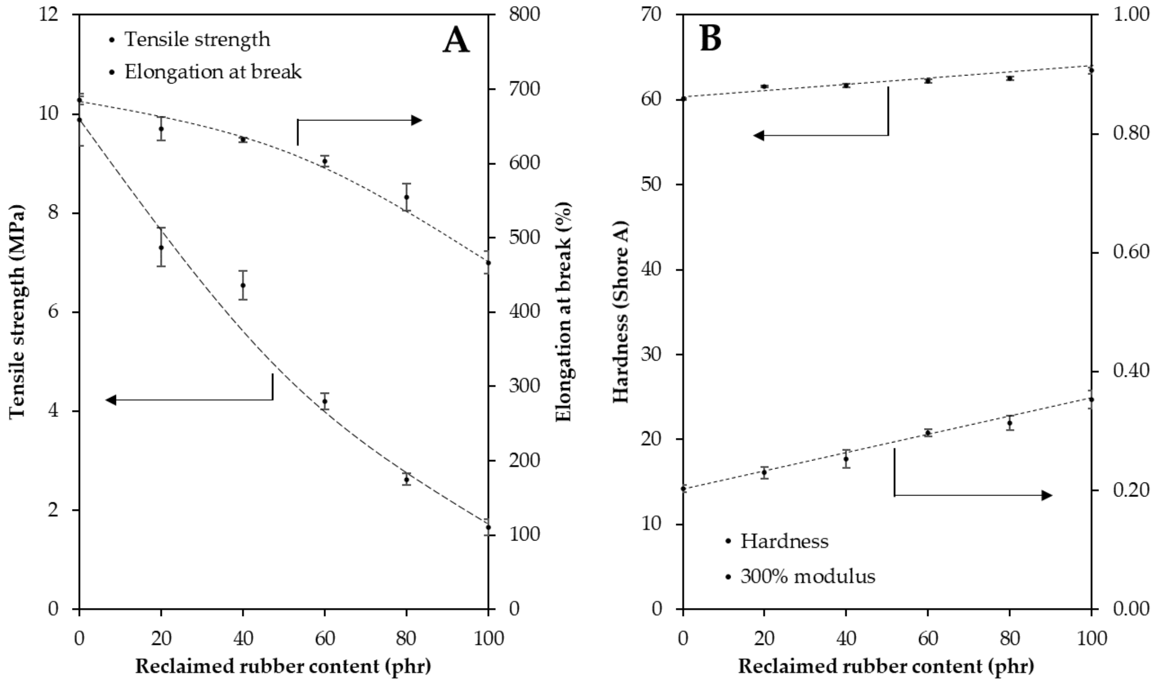

Figure 2. Effect of reclaimed rubber content on tensile strength, elongation at break (A), hardness, and 300% modulus (B).

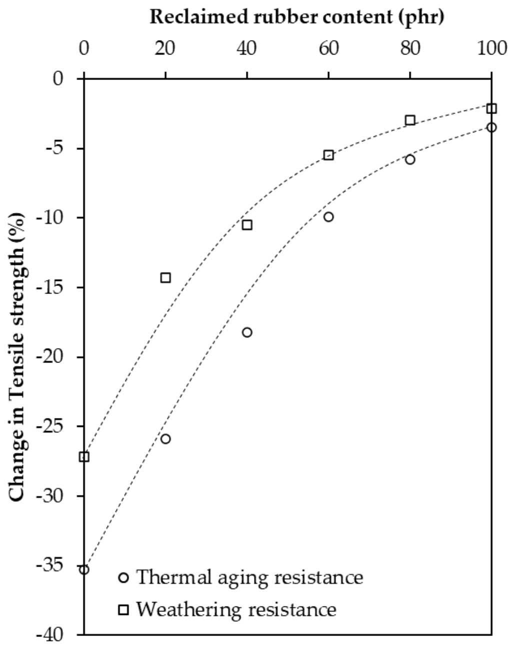

Figure 3. Effect of Reclaimed Rubber Content on the Aging Behavior of Vulcanized Rubber.

The aging behavior of vulcanized rubber blends was evaluated via accelerated thermal and UV aging tests (Figure 3). The percentage decrease in tensile strength due to aging was found to diminish as reclaimed rubber content increased, indicating improved resistance to aging. This can be explained by the degradation mechanism: aging typically involves oxidative cleavage of double bonds, resulting in a reduction of tensile strength. Reclaimed rubber, derived from used tires, contains residual anti-aging agents and a reduced concentration of double bonds. Together, these factors enhance aging resistance and potentially reduce the need for added antioxidants in future product formulations [9].

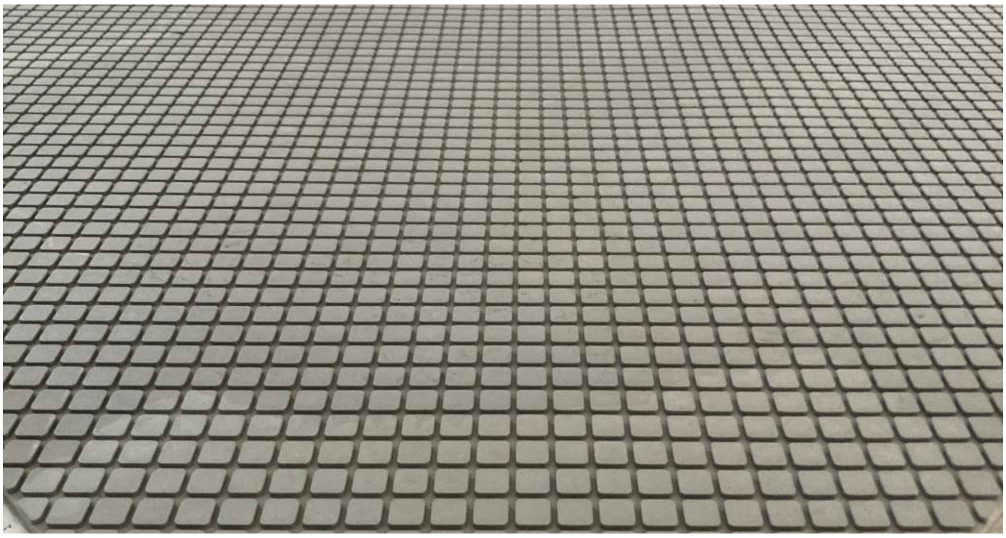

Figure 4. Molding process of outdoor rubber walkway products.

Figure 5. Nai Susn Sri Café has outdoor walkway rubber flooring installed.

Based on the study of the effects of reclaimed rubber content on the mechanical properties and resistance to degradation from both heat and UV radiation, the results were used to develop an outdoor walkway rubber flooring product. The selected rubber formulation contained 100 phr of reclaimed rubber. Although the tensile strength test results were quite low, the material remained sufficiently strong for practical use. At the same time, excellent resistance to degradation is essential for outdoor walkway applications. The molded product was a rubber tile with dimensions of 1 square meter and a thickness of 0.06 meters. Its surface featured a lozenge-shaped pattern to provide slip resistance. The molding process was carried out at a temperature of 170°C for 8 minutes. The resulting product is shown in Figure 4. The outdoor walkway rubber flooring was then tested in a real-life application at "**Nai Susn Sri**," a cozy, homemade-style café located in Srinakarin District, Phatthalung Province. The café features a spacious area with various engaging activities for customers, as well as beautiful photo spots. After installing the rubber walkway around the café, the atmosphere transformed, as shown in Figure 5. The design of the walkway complements the café's overall aesthetic very well. When gathering feedback from users—primarily the café's customers—most expressed high satisfaction with their first impression of the rubber flooring, noting its soft and comfortable feel underfoot throughout the path. Families, particularly those with elderly mothers or young children, appreciated the walkway even more, as it made them feel safer while walking around the premises. Using reclaimed rubber can lower production costs by approximately 30% because it replaces a portion of expensive virgin rubber with a material that has already been processed, thereby reducing both raw material and energy expenses. At the same time, it supports sustainability by diverting end-of-life tires and other rubber waste from landfills and incineration, conserving natural resources, and cutting greenhouse-gas emissions associated with harvesting latex and manufacturing new rubber. This combination of significant cost savings and reduced environmental impact makes reclaimed rubber an attractive option for manufacturers seeking both economic and ecological benefits.

4. Conclusions

This study successfully developed outdoor walkway flooring from natural rubber/reclaimed rubber blends, demonstrating that reclaimed rubber content significantly influences both mechanical properties and aging resistance. Experimental results showed that increasing the reclaimed rubber content from 0 to 100 phr progressively reduced tensile strength and elongation at break, due to the shortened molecular chains resulting from the recycling process. Conversely, hardness and 300% modulus exhibited slight increases attributed to residual cross-links and elevated filler concentrations inherent in reclaimed rubber. Accelerated aging tests revealed that reclaimed rubber incorporation markedly enhanced environmental resistance. The percentage decrease in tensile strength after thermal aging (100°C, 22 hours) and UV aging (0.89 W/m² at 340 nm, 168 hours) diminished progressively with increasing reclaimed rubber content. This superior aging resistance stems from the presence of residual anti-aging agents and reduced concentrations of double bonds in reclaimed rubber. Based on a comprehensive evaluation, the formulation containing 100 parts per hundred rubber (phr) of reclaimed rubber was selected for commercial production. Although the tensile strength was lower than that of virgin natural rubber formulations, the material maintained adequate mechanical performance for practical applications while demonstrating exceptional degradation resistance, essential for outdoor environments. Commercial implementation at Nai Susn Sri Café in Phatthalung Province validated the product's performance, with users reporting high satisfaction regarding comfort and safety, particularly among elderly customers and families with young children. The technology transfer to community entrepreneurs generated measurable socioeconomic benefits, including approximately 30% production cost reduction, increased customer visits, enhanced local product sales, and improved accessibility for elderly and disabled individuals. These outcomes align with UN Sustainable Development Goals 1 and 3, contributing to poverty alleviation and promoting well-being across all age groups.

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Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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